Water Use and Regulation of the Lloyd Aquifer on Long Island, New York

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Abstract
The Lloyd Aquifer is the deepest of the four major aquifers on Long Island and contains groundwater that is up to thousands of years old and in many places of pristine quality. This aquifer is used extensively in Nassau County and minimally in Suffolk County as a source of public water supply. The aquifer is threatened by increasing saltwater intrusion and migration of chemical contamination from aquifer segments in the overlying Upper Glacial and Magothy Aquifers. This report examines the hydrogeological condition of the aquifer, water quality, pumpage, the 1986 Moratorium on new Lloyd Aquifer wells, recharge, and monitoring programs. The report also identifies investigations that are needed to further evaluate the condition of the Lloyd Aquifer including the determination of "managed yield" and "water budget" and to further evaluate of saltwater intrusion. Lastly, this report provides recommendations for amendment of New York State Environmental Conservation Law (ECL) or the issuance of regulatory decisions by the Commissioner of the New York State Department of Environmental Conservation (NYSDEC) to improve protection of the Lloyd Aquifer and the North Shore aquifer, which is interconnected with the Lloyd Aquifer, for future beneficial and sustainable use.

Introduction

The Long Island aquifer system consists of a sequence of unconsolidated deposits of Late Cretaceous and Pleistocene Age that rest on bedrock beneath Kings (Brooklyn) and Queens Counties in New York City and Nassau and Suffolk Counties to the east. This groundwater system contains four major aquifers – the Upper Glacial, Jameco, Magothy and the Lloyd Aquifers (the Lloyd Aquifer being the deepest of the major aquifers). These aquifers provide the water supply that is used for drinking, domestic, commercial, industrial, agricultural, institutional, and fire-fighting uses by residents of Nassau and Suffolk Counties.

The Long Island groundwater system has been designated by the United States Environmental Protection Agency (USEPA) to consist of the Sole Source Aquifers (SSA) of Brooklyn-Queens and Nassau-Suffolk, as authorized under Section 1424(e) of the Safe Drinking Water Act of 1974. The USEPA defines a sole or principal source aquifer as an aquifer which supplies at least fifty percent (50%) of the drinking water consumed in the area overlying the aquifer with no reasonably available alternative drinking water sources should the aquifer become contaminated. The SSA program enables the USEPA to designate an aquifer as a sole source of drinking water and establish a review area that includes the area overlying the SSA, to ensure that proposed projects that receive federal funding do not contaminate the SSA.

The Upper Glacial and Magothy Aquifers have been contaminated in many areas by discharges from industrial, commercial, and residential sources of pollution that include sewage, fertilizers, toxic waste water discharges, and petroleum and chemical leaks and spills. The Lloyd Aquifer has also been impacted in several locations by discharges that have migrated from the Upper Glacial and Magothy Aquifers and by over-pumping that has contributed to increased saltwater intrusion in coastal areas. In recognition of the fragile nature of the Lloyd Aquifer and the increasing threat of saltwater intrusion, New York State enacted a Moratorium in 1986 on the installation of new public, private, and industrial supply wells in the Lloyd Aquifer so as to preserve the aquifer for use

This report examines the quality of groundwater in the Lloyd Aquifer, the quantity of supply well pumping, the estimated aquifer recharge, saltwater intrusion investigations, monitoring programs, and aquifer management and protection needs, in accordance with the Nassau County and Suffolk County 2014 legislation that established the Long Island Commission for Aquifer Protection (LICAP).

Background Information

United States Geological Survey Investigations and Reports

The United States Geological Survey (USGS) has completed extensive investigations of the Lloyd Aquifer on Long Island are identified and summarized by the USGS (Chu, 2006). This report states that the earliest comprehensive study of Long Island's groundwater resources was done by Veatch et al (1906) who were the first to name a stratigraphic deposit from Lloyd Neck as the Lloyd Aquifer. Chu (2006) identified subsequent USGS reports that estimated hydraulic properties, potential groundwater yield, regional rates of groundwater movement, and the age of groundwater in the four aquifers including the Lloyd Aquifer. The USGS has mapped Long Island's geologic units, thickness, water table, and potentiometric-surface altitudes of the Upper Glacial, Magothy and Lloyd Aquifers and has reported pumping of the Lloyd Aquifer in western Long Island. The USGS has also studied the geology and groundwater conditions in southern Nassau and southeastern Queens Counties and has demonstrated that the Lloyd Aquifer is hydraulically separated from the overlying units and contains fresh water.

Hydrogeology

The USGS (Chu, 2006) reports that the Lloyd Aquifer (Lloyd Sand Member of the Cretaceous Age formation) on Long Island extends from central Kings, northwestern Queens and Nassau Counties and northeastern Suffolk County to the east and south. The aquifer deposits may be clear, white, yellow, or grey and consist of a fine to coarse sand and gravel with layers of clay, fine sandy clay, and clayey sand that give it moderate to low permeability. The Lloyd Aquifer rests upon a bedrock surface, is completely bounded above by the Raritan confining unit (or Raritan Clay) which has very low permeability and is considered by the USGS to be the only fully confined aquifer on Long Island (Chu, 2006). The Lloyd Aquifer thickness varies from zero in northern Kings County to over 500 feet in south central Suffolk County. The depth to the top of the aquifer ranges from about 200 to about 1,500 feet below sea level (FBSL) (Olcott, 1995).

Groundwater Withdrawal

The aquifers beneath Long Island have been used for water supply purposes for hundreds of years. According to the USGS (Nemickas, Mallard & Reilly, 1989), in the mid-17th century, virtually every house had its own shallow well that tapped the uppermost unconsolidated geologic deposits and also had its own cesspool that returned wastewater to the same deposits. By the end of the 19th century, as population increased, individual wells in some areas had been abandoned in favor of shallow public supply wells. During the first half of the 20th century, the contamination resulting from increased wastewater discharges led to the eventual abandonment of many domestic and shallow public supply wells for deeper high capacity wells. By the 1930s, over-pumping in Kings County had induced saltwater intrusion and, in 1947, all pumping for public supply in Kings County was stopped to prevent further saltwater intrusion and replaced with water from upstate reservoirs (Buxton and Smolensky, 1998). The introduction of large-scale sewer systems in more heavily populated areas during the 1950s, which protected the aquifers from further contamination, diverted sewage to treatment plants, the bays, and the Atlantic Ocean, thereby, lowering the water table and reducing or eliminating stream flow.

Between 1887 and 1996, the Jamaica Water Supply Company (JWS) operated public supply wells that served communities in southeast Queens and western Nassau Counties (New York City Department of Environmental Protection [NYCDEP], 2015). In 1996, the NYCDEP purchased the Queens County portion of JWS to serve area residents but these supply wells have not discharged water to the distribution system since 2007. The NYSDEC has reported no pumping of Queens County Lloyd Aquifer public supply wells during the period of 1996-2014 (Leung and Pilewski, 2016).

The USGS (Cartwright, 2002) refers to a 1993 potentiometric-surface map of the Lloyd Aquifer in Kings, Queens and western Nassau Countiesy (Plate 6 of Buxton and Shernoff, 1995). The map shows water levels at 20 wells (only one of which is in Kings County) and reveals a large 20 foot depression centered around four Lloyd Aquifer public supply wells in Queens County, extending from western Nassau and eastern Kings Counties. By 1996, water levels had recovered by 19 feet (ft.) to 35 ft., as a result of a 1994 reduction in pumping to a combined total of about 54,000 gallons per day (Cartwright, 2002).

Table 1 identifies 46 Lloyd Aquifer public water supply (PWS) wells located in 18 public water systems in Queens, Nassau and Suffolk Counties (Leung and Pilewski, 2016; Young, 2016). The list provides the local and NYSDEC well number, depth, and capacity in gallons per minute (GPM) and includes four Lloyd Aquifer wells in Queens County, 37 in Nassau County, and five in Suffolk County. Figures 1 and 2 show the location of these wells and select observation wells in Kings, Queens, Nassau, and Suffolk Counties, which are referred to later in this report.

Table 1
Long Island Lloyd Sands Aquifer Public Water Supply Wells

PWS	WELL	DEC #	DEPTH	GPM	PWS	WELL	DEC #	DEPTH	GPM
QUEENS COUNTY					SUFFOLK COUNTY				
NYCDEP: Richmond Hills	17	Q-000317	552	1300	VA Medical Center: Northport	2	S-000049	728	150
NYCDEP: Jamaica	6 C	Q-000562	607	1800	VA Medical Center: Northport	1 A	S-120919	744	150
NYCDEP: Jamaica	18 A	Q-000567	627	1200	SCWA: Huntington	13 A	S-125865	588	450
NYCDEP: Richmond Hills	8 A	Q-003069	555	1000	SCWA: Huntington	14 A	S-126915	568	450
					SCWA: Huntington	15 A	S-129116	530	750
NASSAU COUNTY									
Bayville (Village)	1-1	N-07620	480	1000	Manhasset Lakeville Water District	East Shore Road 5	N-09308	255	1400
Bayville (Village)	1-3	N-08776	459	1000	Manhasset Lakeville Water District	Valley Road	N-12802	408	1400
Bayville (Village)	2-1	N-10144	374	1000	Manhasset Lakeville Water District	Lakeville Road 7	N-13749	567	950
Jericho Water District	11	N-05201	504	1200	Mill Neck Estates	1	N-06042	340	60
Lido-Point Lookout Water District	3	N-08534	1275	1200	Mill Neck Estates	2	N-08426	360	160
Lido-Point Lookout Water District	1 A	N-12217	1277	1200	NYAW - Lynbrook (Atlantic Beach)	6-1	N-04405	620	1400
Lido-Point Lookout Water District	2 A	N-12218	1285	1200	NYAW - Sea Cliff	2	N-07857	614	1400
Locust Valley Water District	4	N-00118	465	1250	Port Washington Water District	N-1	N-01715	480	510
Locust Valley Water District	5	N-00119	570	1600	Port Washington Water District	N-2	N-01716	483	550
Locust Valley Water District	6	N-01651	465	1000	Seawanhaka (Centre Island)	1	N-13532	450	30
Long Beach (City)	9	N-02597	1235	1250	Split Rock	2	N-12525	Unknown (U)	U
Long Beach (City)	11	N-05308	1221	1250	Water Authority of Western Nassau	16 A	N-10958	722	1100
Long Beach (City)	12	N-06450	1275	1250	WAGNN	5	N-00687	310	750
Long Beach (City)	13	N-07776	1226	1180	WAGNN	6	N-01298	342	1000
Long Beach (City)	15	N-08233	1224	1250	WAGNN	7	N-02214	290	850
Long Beach (City)	16	N-08557	1252	1250	WAGNN	8	N-03443	463	1000
Long Beach (City)	17	N-13004	1273	1200	WAGNN	11	N-08342	434	1000
Long Beach (City)	18	N-13475	1285	1250	Westbury Water District	9	N-02602	805	1000

Manhasset Lakeville Water District	SR 1	N-01328	746	1050					

Note: SCWA – Suffolk County Water Authority; VA Medical Center – Veterans Administration Medical Center; NYAW – New York American Water; WAGNN – Water Authority of Great Neck North.

Table 2 summarizes the quantity of Lloyd Aquifer public supply well pumpage in millions of gallons per day (MGD) during 19 years of NYSDEC records from 1996 to 2014 (Pilewski, 2016) and compares it to the USGS (Chu, 2006) historical annual average and maximum (peak year) pumping from the Lloyd Aquifer in Kings, Queens, Nassau and Suffolk Counties up to 1995. This table reveals a decrease in the Long Island average annual Lloyd Aquifer well pumping from 13.84 to 11.3 MGD and a decrease from 28.7 to 14.1 MGD in the total peak year pumping, resulting from the discontinuation of pumping in King and Queens Counties and a significant reduction in peak year pumping in Nassau County.

Table 2
Historical Lloyd Aquifer Public Supply Well Peak Pumpage

County/Area	Average Annual MGD (Up to 1995)	Average Annual MGD (1996-2014)	Maximum Annual MGD (Up to 1995)	Maximum Annual MGD (1996-2014)
Kings	0.74 (1929-46)	0	3.0 (1931)	0
Queens	4.1 (1920-95)[1]	0	8.2 (1944)	0
Nassau	9.0 (1920-95)	10.9	17.5 (1971)	13.3 (2012)
Suffolk	NR[2]	0.4	NR	0.6 (2007)
Long Island[3]	13.84	11.3	28.7	14.1

Note: [1] Excludes 0 MGD in 1993; [2] NR – Not Reported; [3]Sum of the Average Annual (MGD) or Maximum Annual (MGD) pumping in each county during pumping periods.

Also, the NYSDEC (Leung and Pilewski, 2015) reported that Lloyd Aquifer public supply well pumping in Nassau County, for the 15-year period of 2000–2014, averaged 10.6 MGD, approximately 6% of the 189 MGD average annual public supply well pumping in Nassau County during those years.

Lloyd Aquifer Recharge

The USGS (Chu, 2006) reports that the Lloyd Aquifer contains about 9% of Long Island's fresh water but receives only 3.1% of the recharge through a narrow corridor that is only 0.5 mile wide along the groundwater divide in Kings, Queens, Nassau and Suffolk Counties. The USGS has also estimated that the annual recharge to the Long Island aquifer system is approximately 50% of total precipitation (Petersen, 1986); and has defined the "water-budget area" for Long Island (Cohen, et al, 1968) as including about 760 square miles in Nassau and Suffolk Counties excluding the north and south forks in Suffolk County. (Kings and Queens Counties are excluded from the water-budget area because of intensive urbanization and other related factors).

Since the average annual precipitation on Long Island is 45 inches per year (Petersen, 1986), it may be estimated that the total recharge to all aquifers in the "water-budget area" is approximately 814 MGD with approximately 25.25 MGD (3.1%) recharging the Lloyd Aquifer. This estimate of recharge, however, may not consider all of the water lost due to outflow from the Lloyd Aquifer, which for Nassau County has been reported to be as high as 6 MGD (Nassau County, 1998). It is also important to note that as the total volume of freshwater in the Magothy and Upper Glacial Aquifer declines, the amount of water that recharges the Lloyd Aquifer also declines. A distribution of the total estimated Lloyd Aquifer recharge in proportion to the effective recharge areas indicates that Lloyd Aquifer recharge is approximately 7.25 MGD (29%) in Nassau County and 18.0 MGD (71%) in Suffolk County.

The average annual Lloyd Aquifer pumping in Nassau County (10.9 MGD) substantially exceeds the estimated Lloyd Aquifer recharge (7.25 MGD) indicating a significant deficit (3.65 MGD) condition that is producing a reduction in Lloyd Aquifer storage and, hence, inducing saltwater intrusion. This deficit and reduction in storage may be even greater than 3.65 MGD depending upon the actual amount of aquifer outflow. It should be noted that these estimates do not include any inflow or outflow across county borders. The threat of a reduction in Lloyd Aquifer storage and eventual depletion has been recognized by NYCDEP when it warned in 2007 that "Currently, the Lloyd Aquifer's resources are depleting, mainly due to the rate of consumption by Long Island communities that is greater than the rate of natural recharge." In Suffolk County, the average annual Lloyd Aquifer pumping (0.4 MGD) is well below the estimated Lloyd Aquifer recharge (17.75 MGD), also not considering outflow losses.

Water Budget, Safe Yield, and Managed Yield

The "water-budget" and "safe yield" concepts have been described as alternative methods of developing and managing the water resources of Long Island (Cohen, et al, 1968) as summarized in the basic "water-budget" equation: Inflow = Outflow ± Change in Storage. "Safe yield" is commonly defined as the volume of groundwater which can be withdrawn annually without producing an undesired result; and has been used to categorize withdrawals as "safe" if they do not exceed the annual rate of recharge to the aquifer. However, this approach may be considered flawed because it fails to incorporate other processes occurring in the aquifer such as natural outflow. A new approach defined as "managed yield" (Meyland, 2011) is suggested as a replacement for "safe yield" when developing management strategies for groundwater systems.

"Managed yield" may be defined as the amount of water a community identifies as available from an aquifer system, including a safety margin, so that aquifer changes do not reach a point where undesirable consequences can occur. The "managed yield" approach to aquifer management requires that a full water budget analysis be conducted accounting for inflow, outflow, and changes in storage and the identification of adverse aquifer impacts, including water table and stream flow changes and saltwater intrusion. This approach also requires the community determination of the undesirable consequences of aquifer pumping, establishment of goals, and a plan for avoiding, correcting, or reducing adverse impacts as may be feasible. When fully implemented, "managed yield" will improve the protection of an aquifer and may enable a reduction or reversal of some of the adverse impacts that have already occurred as a result of over pumping.

Lloyd Aquifer Public Supply Well Quality

Table 3 lists the highest concentration of select chemical constituents detected in the most recently available testing of Lloyd Aquifer public supply wells in Queens County (Cartwright, 2002), Nassau County (Young, 2016) and Suffolk County (Hime, 2016). The NYCDEP (2015) has reported the following range of contaminants in the Queens County groundwater supply system but has not reported the range of contaminants in Lloyd Aquifer supply wells that are a part of the system: Iron: ND to 18.9 parts per million (ppm); Manganese: ND to 3.3 ppm; Nitrate: ND to 12.0 ppm; Volatile Organic Compounds (VOCs): ND to 3,170 parts per billion (ppb).

Table 3
Lloyd Aquifer Public Supply Well Testing Results
Highest Levels of Select Contaminants

	Chloride (mg/L)	Iron (mg/L)	Nitrate (mg/L)	Perchlorate (mg/L)	VOCs (ug/L)
MCL/PAL	250	0.3	10.0	18	5
County					
Kings	N/A	N/A	N/A	N/A	N/A
Queens (1992/96)	22	NR	1.30	NR	23.9 (*TTHMs*)
Nassau (2013-2015)	141	13	4.33	1.1	29.8 (*Freon 22*)
Suffolk (2013-2015)	11	0.12	4.5	1.9	4.4 *(TCE*)

Note: mg/L - milligrams per Liter; ug/L – micrograms per Liter; N/A - Not applicable (there are no public supply wells in Kings County); NR - Not Reported; MCL/PAL: Maximum Contaminant Level (Primary Action Level for Perchlorate); TTHMs: Total Trihalomethanes; Freon 22 - Chlorodifluoromethane; TCE – Trichloroethylene.

Chloride

Chloride, which is found in high concentrations in sea water and road salt, has been detected in Lloyd Aquifer public supply wells in Great Neck (42.1 to 141 mg/L) and indicates that saltwater intrusion is occurring. These levels are, however, below the 250 mg/L MCL and the supply wells continue to be used. The level of chloride in Locust Valley Water District Well No. 5 (39.5 mg/L), Queens County Well No. 17 (22 mg/L), and Port Washington Water District Well N-2 (19.1 mg/L) indicate potential saltwater intrusion. The chloride level in five Lloyd Aquifer public supply wells in Suffolk County (6 to 11 mg/L) and 22 Nassau County

Lloyd Aquifer wells in the communities of Atlantic Beach (1), Bayville (3), Jericho (1), Lido-Point Lookout (3), Long Beach (8), Manhasset (4), New Hyde Park (1), and Westbury (1) which have less than 10 mg/L of chloride, reflect pre-development conditions when chloride probably ranged from 3 to 12 mg/L (Cartwright, 2012). (See Tables 4 & 5 for chloride levels in monitoring wells).

Iron

Iron is a naturally occurring mineral that dissolves from aquifer deposits under reducing/oxygen depletion conditions. The highest levels of iron in Lloyd Aquifer public supply wells are found in the barrier beach communities of Atlantic Beach (7.1 mg/L), Long Beach (3.5 to 13 mg/L), and Lido-Point Lookout (3.16 to 4.81 mg/L) and require iron removal treatment. Lloyd Aquifer public supply wells inland and on the north shore of Nassau County have iron levels below 1.0 mg/L (< 0.02 to 0.84 mg/L) as do Suffolk County Lloyd Aquifer public supply wells (<0.1 to 0.12 mg/L).

Nitrate

Nassau and Suffolk County Lloyd Aquifer public supply wells have been impacted to a moderate degree by nitrate contamination which originates from fertilizer and sanitary sewage discharges. These wells, which contain nitrate below the MCL of 10 mg/L, are located in Locust Valley (3.83 to 4.33 mg/L), Huntington and Northport (2.1 to 4.5 mg/L), Great Neck (1.74 to 3.7 mg/L), Mill Neck (1.42 to 1.46 mg/L) and Queens County (1.3 mg/L). Lloyd Aquifer wells in the Nassau County barrier beach communities of Atlantic Beach, Long Beach, and Lido-Point Lookout have the lowest nitrate levels (<0.05 to <1.0 mg/L) and reflect pre-development nitrate levels of less than 0.2 mg/L, measured as nitrogen (Cartwright, 2002).

Volatile Organic Compounds

VOCs are found in industrial chemical solvents, paints, refrigerants, cleaning products, adhesives, and numerous other products that may be toxic or carcinogenic. Trihalomethanes (THMs), which are typically produced by the reaction of chlorine or other disinfectant chemicals with organic material found in sewage, surface water, drainage, or public water supply distribution systems, were the principal VOCs found in Queens County public supply wells where Total THM (TTHM) levels were found at a maximum level of 23.9 ug/L in USGS 1992/1996 testing (Cartwright, 2002). VOCs have also been detected in eight of 37 Lloyd Aquifer public supply wells in Nassau County. This includes: Manhasset-Lakeville Water District Valley Road Well (Freon 22: 29.8 ug/L), which has a VOC removal air stripping tower (AST) treatment; 3 Locust Valley Water District wells (0.6 to 5.8 ug/L) including Well 5, which has granular activated carbon (GAC) treatment; and 4 wells in Great Neck (0.5 to 17 ug/L) including Well 6 and Well 8 that also have ASTs. In Suffolk County, four of five Lloyd Aquifer public supply wells also contain VOCs (0.5 to 4.4 ug/L) but at levels below the MCL of 5 ug/L for an individual VOC.

Perchlorate

Perchlorate, which is a component of rocket fuel, pyrotechnics, and Chilean caliche fertilizer, has been detected in one Lloyd Aquifer public supply well in Nassau County (Locust Valley Water District Well No. 4) at a level of 1.1 ug/L and in one Lloyd Aquifer public supply well in Suffolk County (Northport Veterans Administration Hospital well) at maximum levels of 1.8 and 1.9 ug/L. Perchlorate has not been detected in any of the three SCWA Lloyd Aquifer public supply wells in Huntington.

Saltwater Intrusion

The USGS (Luscynski and Swarzenski, 1966) has reported that salty groundwater occurs in southern Nassau and southeastern Queens Counties as three wedge-like extensions that project landward in unconsolidated deposits from a main body of salty water that lies seaward of the barrier beaches in Nassau County and Jamaica Bay in Queens County. The highest chloride content of the wedges is reported to be approximately 16,000 ppm, which is approaching the typical chloride content of sea water (19,400 ppm). A leading edge of the deep wedge of saltwater intrusion is located at the base of the Magothy Aquifer and at the shoreline east of Lido Beach extending inland about 4 miles to Woodmere and 7 miles to South Ozone Park. The extent of saltwater intrusion in the Lloyd Aquifer, which lies below the Raritan Clay, however, is not known. The USGS report also indicates that along and near the barrier beaches, salty water from the underside of the deep wedge is moving downward very slowly towards the freshwater in the Lloyd Aquifer. The report concludes that the very small increases in chloride detected in Long Beach, Atlantic Beach, and Rockaway Park supply wells suggest downward saltwater intrusion into the Lloyd Aquifer, and possible lateral intrusion from offshore areas to supply wells in the upper beds of the Lloyd Aquifer.

Nassau County reopened a study of saltwater intrusion in 1987 (Fitzgerald and Maimone, Camp Dresser & McKee, 1991) and reported that, although the location of the interface of a saltwater wedge in the Lloyd Aquifer is not known, the use of a saltwater intrusion computer model (DYNSWIM), using an arbitrary assumption that the wedge is located 3 miles offshore, projected very slow rates of advance of less than 30 feet per year and only a one-half mile advance of the wedge over a 100-year period. The

USGS updated previous studies of saltwater intrusion and used a three-dimensional model to simulate saltwater intrusion in the four major aquifers in Kings, Queens, and western Nassau Counties (Terracciano, 1997; Misut, et al, 2002).

Table 4 presents the results of the testing of two Lloyd Aquifer observation wells in Kings County and four of eight observation wells in Queens County in 1992 and/or 1996 (Figure 1) that were found to have the highest chloride testing results as reported by the USGS (Cartwright, 2002).

Table 4
Select Kings and Queens County Lloyd Aquifer Monitoring Well Chloride Testing Results

Observation Well	Location	Chloride (mg/L)	Year
K-2859	Coney Island	54	1992
K-3426	Southern Brooklyn near Queens	8,500	1996
Q-1071	Queens Barrier Beach	56	1992
Q-0287	Jamaica Bay Island (Howard Beach)	120	1992
Q-3657	Southern Queens	10,500	1992
Q-1373	Northern Queens near Flushing Bay	1,300	1996

The chloride levels detected in K-3426, Q-3657, and Q-1373 are far higher than the chloride concentrations detected in coastal Lloyd Aquifer observation wells such as K-2859 in Coney Island, Q-287 in Jamaica Bay, and Q-1071 on the Queens county Barrier Beach. The USGS (Cartwright, 2002) suggests that the cone of depression in southern Queens County generated by public supply withdrawal from the Lloyd Aquifer (Buxton and Shernoff, 1995) has caused inland migration of salt water and that the freshwater-saltwater interface may be about 7 miles farther inland than previously estimated by Buxton and Shernoff.

The USGS has also investigated the extent of saltwater intrusion in the Lloyd Aquifer in northern areas of Nassau County and published three reports (Stumm, 2001; Stumm, et al, 2002; 2004) that provide information regarding the hydrogeological conditions of the aquifer including the water table, potentiometric surface, and saltwater intrusion. A USGS paper (Stumm, 2006) states that the Lloyd Aquifer has been extensively or completely eroded in places and is hydraulically interconnected to a confined Pleistocene Age aquifer (North Shore Aquifer), This report also states that public supply pumping reduced water levels to as much as 40 feet below sea level and over-pumping has induced eight wedges of salt water intrusion into the aquifer. Stumm (2006) states that chloride concentrations in Lloyd Aquifer supply wells ranged from 5 to 10 mg/L and those in the North Shore aquifer were similar. However, six public supply wells (five in the Lloyd Aquifer and one in the North Shore Aquifer) have been shut down due to elevated chloride concentrations. A total of eight salt water wedges have been identified in Great Neck, Manhasset Neck, and Oyster Bay, having peak chloride concentrations ranging from 180 to 13,750 mg/L.

Table 5 presents the results of the Nassau County Department of Public Works (NCDPW, 2005) testing of two Lloyd Aquifer south shore, eight Lloyd Aquifer north shore, and one North Shore (Lloyd Aquifer-interconnected) Aquifer observation wells (Figure 3) that had chloride levels which reflect varying degrees of saltwater intrusion.

Table 5
Select 2003 Chloride Testing Results
Lloyd and North Shore Aquifer Observation Wells (NCDPW, 2005)

Observation Well	Location	Chloride (mg/L)	Aquifer
Q-00287	Howard Beach	145	Lloyd
N-10620	Atlantic Beach	45	Lloyd
N-12076	Kings Point	780	Lloyd
N-12153	Kings Point	5,900	Lloyd
N-12793	Port Washington	112	Lloyd
N-12508	Port Washington	800	Lloyd
N-12318	Sands Point	155	North Shore
N-12618	Bayville	45	Lloyd
N-12790	Bayville	2,850	Lloyd
N-12870	Bayville	108	Lloyd
N-12646	Lattingtown	28	Lloyd

The NCDPW (2005) report also contains a map that shows a 5-foot potentiometric surface depression in the Lloyd and North Shore Aquifers that extends from the southeast corner of Great Neck to the southwest corner of the Manhasset Neck peninsula into the lower area of Hempstead Harbor. This cone of depression suggests that public supply well withdrawals from the Lloyd and North Shore Aquifers has resulted in the inland migration of salt water or salt water wedges as reported by the USGS (Stumm, 2001; and Stumm, et al, 2002; 2004). Chu (2006) reports that nearly all pumping from the Lloyd Aquifer has been in the western part of Long Island and states that the excessive pumpage has led to saltwater intrusion in the Lloyd Aquifer in coastal areas.

NCDPW tested a line of progressively deeper Lloyd Aquifer monitoring wells from Long Beach Island to Jones Beach and Tobay Beach (Busciolano and Terracciano, 2013) that show a trend of low to high to lower chloride levels. The westernmost well in Atlantic Beach (N-13682, 1,237 feet deep) has 42 mg/L of chlorides while the next deeper and easterly well in Long Beach (N-13879, 1,400 ft. deep) has 110 mg/L, showing clear evidence of salt water intrusion. The remaining deeper and more easterly wells from Long Beach (1,500 feet deep and 1,600 feet deep) to Tobay Beach (1,800 feet deep) have lower chloride levels (15, 18, and 6 mg/L, respectively).

There is currently very limited USGS monitoring of groundwater levels and no network of deep outpost wells to monitor saltwater intrusion in Kings and Queens Counties and it has been more than 12 years since the positon of the freshwater-saltwater interface in the Magothy and Lloyd Aquifers was last assessed (done in 2004) (Misut and Voss, 2007). Nassau County has recently provided funding to reinstate the USGS annual well monitoring program; however, that contract will expire on September 30, 2017 (Mangano, 2017). The County has requested that the State provide a permanent annual funding source for the work which totaled $220,000 for the 2016-2017 federal fiscal year.

The Water Authority of Great Neck North (2013) has developed a Water Conservation plan of action to protect its resources. The plan consists of an aggressive conservation program coupled with a comprehensive well management plan. Under this plan, the Authority has constructed 3 operating wells off the peninsula to provide some relief for any saltwater intrusion on the peninsula.

Lloyd Aquifer Moratorium

The New York Environmental Conservation Law (New York ECL) entitled “Moratorium on the drilling of new wells in the Lloyd” (ECL §15-1528 Moratorium, August 2, 1986) established a moratorium on the granting of new permits to drill public water

supply, private water supply, or industrial wells into the Lloyd Aquifer or to permit new withdrawals of water from the Lloyd Aquifer. The Moratorium applies to all areas that are not "coastal communities" but shall apply to all areas including "coastal communities" for the storage or pumping of water into the Lloyd Aquifer. The moratorium requires that the waters of the Lloyd Aquifer be reserved for the use of "coastal communities" but does not affect the permits of wells that were screened in the Lloyd Aquifer and withdrawing water at the time that the moratorium was enacted (1986).

Per ECL §15-1528, the moratorium may only be lifted upon a finding by the Commissioner that sufficient research has been conducted providing a sound working knowledge of the details, dynamics, water volume, and levels of safe withdrawal appropriate to maintain a safe quantity of Lloyd Aquifer water. The Commissioner must also find that a "workable program is in place that can properly administer a well permit program for the Lloyd Sands water. Such program shall take into account both the localized and regional aspects and implications of Lloyd Sands water withdrawals, with special attention given to the prevention of water contamination and salt water intrusion. The program must ensure that a safe level of withdrawal from the Lloyd Sands is not exceeded" (ECL §15-1528 Moratorium).

The NYSDEC has been directed under ECL § 15-1528 to identify those areas of Long Island within the counties of Kings, Queens, Nassau, and Suffolk which for the purpose of that section shall be considered "coastal communities". ECL §15-1502 defines "coastal communities" as meaning those areas on Long Island where the Magothy Aquifer is either absent or contaminated with chlorides. The NYSDEC, however, has not yet undertaken a comprehensive assessment of what constitutes a "coastal community" as required by the statute, thus the delineation at present has to be determined on a case-by-case basis (Grannis, 2007). The NYSDEC commissioner, however, may grant exemptions to the moratorium upon a finding of "just cause and extreme hardship". ECL §15-1528 was amended (September 25, 2008) to also apply to the storage or pumping (recovery) of water into the Lloyd Aquifer.

On April 27, 2004, the NYSDEC determined that a permit application (SCWA, DEC Project No. 1-4700-00010/00583) to install a production well into the Lloyd Aquifer was complete and the application was referred for a hearing by the Department's Region 1 Office (Sanza, 2004). The application requested approval for the proposed construction of a 300 GPM well (No. 3) at the SCWA's Middleville Road well field that would pump Lloyd Aquifer water to blend with water from a Magothy Aquifer well that was contaminated with nitrates. The SCWA application was denied by the NYSDEC in the "Decision of the Commissioner" (Grannis, 2007) which stated that SCWA did not establish that its existing Middleville Road well field was "contaminated with chlorides" and cannot, therefore, be considered an exempt "coastal community" and that SCWA failed to meet the statutory standard of "just cause and extreme hardship". During 2014, 2 new applications for the installation of new Lloyd Aquifer wells were submitted to the NYSDEC by public water suppliers in Nassau County including the Bethpage Water District, which is pending, and the New York American Water-Sea Cliff (NYAW-SC) water system, which was withdrawn on November 3, 2015. NYAW--SC has also submitted a Water Withdrawal Application (WWA) to the NYSDEC to replace the Lloyd Aquifer Well 1 at the Sea Cliff station, which had a screen failure in November 2016, with a replacement Well 1A at the same site. NYAW-SC will insert a new well screen in the existing well as a temporary repair for the 2017 pumping season.

The North Shore Aquifer

The North Shore Aquifer is defined as a sequence of poorly to moderately sorted, dark, olive-brown and olive-gray gravel, sand and silt layers (Stumm, 2001). The aquifer was penetrated during drilling in the northernmost part of Great Neck in 1991-1996 where it was determined that the Lloyd Aquifer, the Raritan confining unit, and the Magothy Aquifer had been completely removed from the northern part of the peninsula by extensive glacial erosion. The North Shore Aquifer name was introduced as a distinct hydrogeologic unit to represent a sequence of Pleistocene-Age sediments that are confined by a Pleistocene-Age clay (North Shore confining unit), that are in contact with bedrock and hydraulically interconnected with the Lloyd Aquifer. The North Shore Aquifer was also investigated in the northernmost and central part of Manhasset Neck (Stumm, Lange, and Candela, 2002) and in the northwestern, central, and northeastern parts of the Town of Oyster Bay (Stumm, Lange, and Candela, 2004).

Stumm (2001) states that the North Shore Aquifer deposits were called the Jameco Gravel and the Port Washington Aquifer by Kilburn and Krulikas (1987). The top of the aquifer ranges from 70 to 90 feet below sea level (FBSL) in the Great Neck peninsula, 70 to 300 FBSL in Manhasset, and 150 to 500 FBSL in the Town of Oyster Bay. The aquifer thickness ranges from as little as 5 to 10 feet to more than 150 feet thick in Great Neck; 50 to 150 feet thick in Manhasset; and 100 to 230 feet thick in Oyster Bay. The rapid response of water levels to tides and/or pumping indicates the North Shore Aquifer is moderately permeable and confined (except for one area in Manhasset, where it appears to be semi-confined) (Stumm, Lange, and Candela, 2002). Both the North Shore and the Lloyd Aquifers are impacted by pumping and tidal effects and vulnerable to saltwater intrusion.

Long Island Groundwater Study

On February 25, 2016, Governor Andrew Cuomo announced a series of water quality initiatives, which will include a $6 million Long Island study conducted by the USGS for the management of groundwater across Long Island (Nikic, 2016). An NYSDEC (April 2016) statement indicated that the purpose of the USGS study is to create an updated and enhanced Long Island Regional Groundwater Flow modelling tool for use by the USGS, NYSDEC, Nassau County, Suffolk County, and other key water resources management partners in the region. This will enable better management of the region's groundwater resources, including, but not limited to, managing for over-pumping, saltwater intrusion, saltwater upconing, plume migration, surface water impacts of groundwater outflow, and determining safe-yield. The study will also update the hydrogeologic framework of Long Island to obtain a better understanding of groundwater flow and include the installation of a network of deep Lloyd and Magothy Aquifer observation wells to augment the current monitoring well network and determine the current and predicted future extents of salt water intrusion and salt water upconing.

Aquifer Management

The NYSDEC is the agency that has the responsibility of managing the water resources of New York State and enforcing the requirements of the ECL so as to protect the Lloyd Aquifer from the adverse impacts described in this report. The NYSDEC implements water supply protection programs on Long Island and the Water Withdrawal Application (WWA) permitting program to assure that groundwater resources are properly managed and allocated. The NYSDEC role is critical in assuring that the Lloyd Aquifer is protected and withdrawals allocated in a manner that will preserve this resource. This report will discuss and present recommendations for the improved management and protection of the Lloyd Aquifer for consideration by the Long Island Commission for Aquifer Protection and the State of New York.

Discussion and Conclusions

1. The 1986 Lloyd Aquifer ECL §15-1528 Moratorium has been in place for over 30 years to prevent the installation of new Lloyd Aquifer wells in non-coastal communities. This has helped preserve the aquifer for those communities that have no other cost-effective source of public water supply. The Moratorium must be continued in the absence of a finding by the NYSDEC Commissioner that a workable program is in place to properly administer a well permit program for the Lloyd Aquifer water with special attention to the prevention of water contamination and saltwater intrusion. The program must ensure that a safe level of withdrawal from the Lloyd Aquifer is not exceeded. The absence of such a finding by the NYSDEC Commissioner and evidence of continued over-pumping of the Lloyd Aquifer that promotes water contamination and increasing salt water intrusion requires that additional measures be taken to protect and preserve the aquifer and ensure that a safe level of withdrawal does not continue to be exceeded.
2. The reactivation of Lloyd Aquifer supply wells, which have not been used for extended periods in areas where other cost-effective sources of water supply are available, will promote increased saltwater intrusion. This will be the case in Queens County if the NYCDEP reactivates four Lloyd Aquifer public supply wells that pumped an average of 4.1 MGD of water from 1920-1995 (for a total withdrawal of 112 billion gallons) and where a 20 ft. depression in the potentiometric surface of the aquifer resulted (Cartwright, 2002). This depression extended into western Nassau and eastern Kings Counties. This over-pumping occurred in Queens County where there are combined sewers that discharge storm water and sewage to treatment plants with outfalls to the surrounding water bodies. In these areas, groundwater recharge by precipitation is vastly reduced and the major source of recharge water to the aquifer is leakage from water supply and sewer lines (Buxton and Smolensky, 1998).
3. Although NYC indicates that the reactivation of the Queens County groundwater system is no longer required as part of the ("Water for the Future") water supply augmentation plan to meet the anticipated water demands during the shutdown of the Delaware aqueduct planned in 2021 (NYC MFA, 2016), the NYCDEP, however, plans to renew the Queens County groundwater withdrawal permits in 2017 for added protection against drought or other emergency. Inasmuch as NYC now has surface water sources available that provide 1 billion gallons per day of water supply, the NYSDEC should not allow NYC to renew permits for the Lloyd Aquifer public supply wells that are part of their groundwater system because the Lloyd Aquifer has previously been over-pumped and impacted by severe saltwater intrusion created by the historical over-pumping of the aquifer in Queens County.
4. Actions are needed to significantly reduce the pumping of Lloyd Aquifer public supply wells in Nassau County where the estimated quantity of Lloyd Aquifer pumping exceeds the estimated recharge, not considering all the water lost due to aquifer outflow. If the Lloyd Aquifer is to be preserved for "coastal communities", as defined in ECL §15-1502, then it is reasonable to not only continue to prohibit the issuance of new permits for Lloyd Aquifer wells under the ECL Moratorium but it is also necessary to assure that existing Lloyd Aquifer supply wells that fail are not relocated, replaced, or re-drilled in non-"coastal communities" or where other cost effective sources of water supply are available.

This action, which, over time, will help reduce pumping from the Lloyd Aquifer, can be accomplished by a revision or clarification of the ECL §15-1528 statute or by a regulatory decision of the Commissioner of the NYSDEC.

5. Public water suppliers who rely on the use of Lloyd Aquifer wells in areas that have not been designated as "coastal communities" by the NYSDEC should be encouraged to replace the capacity of these wells before they fail. Incentives should be considered to encourage water suppliers to drill replacement wells in overlying aquifers. These incentives could take the form of financial grants to offset potential treatment costs or other means to discourage the continued use of Lloyd Aquifer wells in areas where other aquifers are available.
6. The USGS has determined that the North Shore Aquifer is hydraulically interconnected with the Lloyd Aquifer and responds to pumping and tidal effects in the same manner as the Lloyd Aquifer. It is therefore essential that this aquifer be protected from over-pumping, saltwater intrusion, and migration of contamination, in the same way the Lloyd Aquifer is now protected, by limiting the use of the aquifer to water suppliers who have no other cost-effective source of public water supply. This can be achieved by the enactment of new State legislation, expansion of the Lloyd Aquifer ECL §15-1528 Moratorium, or by a regulatory decision of the Commissioner of the NYSDEC that will prevent the installation of new, deepened, re-drilled, relocated, or replacement wells into the North Shore Aquifer in areas that have not been identified as "coastal communities" by the NYSDEC.
7. There is a need for the permanent funding of groundwater quality and water level monitoring programs conducted by the USGS on Long Island. Additional and updated studies of the location of the freshwater-saltwater interface in the Lloyd Aquifer in Queens, Nassau, and Suffolk Counties are also critically needed, as described by the NYSDEC (2016) to update information on the location and movement of the freshwater-saltwater interface in the Magothy and Lloyd Aquifers. The impacts of localized pumping and saltwater intrusion should be studied by performing "water budget" and "managed yield" analyses and appropriate computer modeling to determine the allowable quantity and location of Lloyd and North Shore Aquifer pumping to prevent continuing saltwater intrusion, contamination migration, depletion, or other adverse aquifer impacts. This information should be evaluated by the NYSDEC to improve the management and protection of Long Island groundwater resources.

Recommendations

The Long Island Commission for Aquifer Protection (LICAP) is urged to recommend the following actions to protect the Lloyd and North Shore Aquifers from over-pumping, salt water intrusion, migration or leakage of chemical contamination, depletion, and other adverse aquifer impacts:

1. That the State of New York amend the ECL§15-1528 "Moratorium" on the drilling of new wells in the Lloyd Aquifer (August 2, 1986) (the "Moratorium") or that the Commissioner of the NYSDEC issue a regulatory decision, to prohibit the renewal of any NYSDEC well permit for the operation or reactivation of any Lloyd Aquifer public supply well, private water supply, or industrial well that has not been used for 5 or more years in areas not identified as "coastal communities", as defined by ECL §15-1502.
2. That the State of New York amend the ECL §15-1528 "Moratorium" or that the Commissioner of the NYSDEC issue a regulatory decision to prohibit the replacement, relocation, deepening, or re-drilling of any Lloyd Aquifer public supply well, private water supply, or industrial well in areas not identified as "coastal communities". It is also recommended that LICAP work with all water suppliers who are affected by this requirement and may face hardships as they plan for the long term eventual "phase out" of Lloyd Aquifer wells and their replacement with wells located in overlying aquifers.
3. That the State of New York enact new legislation, amend the ECL §15-1528 "Moratorium", or that the Commissioner of the NYSDEC issue a regulatory decision to prohibit the installation of new, replacement, re-drilled, or relocated North Shore Aquifer public, private water supply, or industrial wells, as may be identified or classified by the NYSDEC, in areas not identified as "coastal communities", on the basis that the North Shore Aquifer has been determined by the USGS to be hydraulically interconnected with the Lloyd Aquifer, which should be reserved and protected for use by "coastal communities," as defined by ECL §15-1502.
4. That the State of New York provide a permanent annual funding source to continue the USGS annual well monitoring program and consider the enactment of legislation that would provide on-going funding for continued research and improved management of the groundwater resources of Long Island to help preserve and protect the Lloyd and North Shore Aquifers and water resources of Long Island for future beneficial and sustainable use.

Summary

This report examines the Lloyd Aquifer pumping, recharge, quality, saltwater intrusion studies, the ECL Moratorium on the installation of new wells, and the North Shore Aquifer and provides recommendations for improved aquifer regulations, monitoring, investigations, management, and protection. There are a total of 46 Lloyd Aquifer public supply wells on Long Island. Four are inactive in Queens County; 37 are in Nassau County; and five are in Suffolk County. These wells withdrew an average

of 11.3 MGD of groundwater from the aquifer between 1996 and 2014. This represents a decline of 2.5 MGD in the average annual pumping of Kings, Queens, Nassau and Suffolk County Lloyd Aquifer public supply wells for periods of pumping up to 1995. In Nassau County, Lloyd Aquifer pumping from 2000 to 2014 averaged 10.6 MGD and represented 6% of the average annual public supply well pumping of 189 MGD during that period.

The USGS has completed the most extensive research on the hydrogeology, pumping, recharge, and monitoring of the Lloyd Aquifer, as summarized by Chu (2006). The Lloyd Aquifer has been estimated to contain about 9% of Long Island's fresh water supply but receives only 3.1% of the recharge through a narrow corridor that is only 0.5 miles wide. The water budget or effective recharge area is 760 square miles (Cohen, et al, 1968) and it may be estimated that the overall Lloyd Aquifer recharge is approximately 25.25 MGD including 7.25 MGD (29%) in Nassau County and 18 MGD (71%) in Suffolk County.

The average annual Lloyd Aquifer pumping in Nassau County (10.9 MGD) substantially exceeds the estimated Lloyd Aquifer recharge (7.25 MGD), indicating a significant deficit (at least 3.65 MGD), and causing a reduction in Lloyd Aquifer storage and inducing saltwater intrusion, which may eventually lead to aquifer depletion. In Suffolk County, the average annual Lloyd Aquifer pumping (0.4 MGD) is well below the estimated Lloyd Aquifer recharge (18 MGD), also not considering all of the water that is lost due to aquifer outflow.

Water quality data from Lloyd Aquifer public supply well testing in Nassau, Suffolk, and Queens Counties, showed the highest level of chloride in Lloyd Aquifer public supply wells in five Great Neck wells. Chlorides ranged from 42 to 141 mg/L, indicating significant saltwater intrusion in the peninsula. VOCs, Trihalomethanes, and nitrate were also detected in Lloyd Aquifer public supply wells. Iron concentrations ranged from less than 1.0 mg/L in Suffolk and Nassau County inland and north shore locations to as high as 13 mg/L in Long Beach.

The most significant Lloyd Aquifer water quality problem is saltwater intrusion. This problem has been investigated by the USGS (Luscynski and Swarzenski, 1966) which reports that salty groundwater occurs in southern Nassau and southeastern Queens Counties as three wedge-like extensions that project landward in unconsolidated deposits from a main body of salty water that lies seaward of the Nassau County barrier beaches and Jamaica Bay. The highest chloride contents of the wedges are reported to be approximately 16,000 ppm, which is approaching the typical chloride content of sea water (19,400 ppm). The report also indicates that, along and near the barrier beaches, salty water from the underside of the deep wedge is moving downward very slowly towards the freshwater in the Lloyd Aquifer.

The USGS (Cartwright, 2002) results of Lloyd Aquifer observation well testing revealed significant saltwater intrusion near Coney Island (54 mg/L), the Queens County Barrier Beach (56 mg/L), and Howard Beach (120 mg/L), and detected severe chloride intrusion in southeastern Brooklyn (8,500 mg/L) and southern Queens County (10,500 mg/L). The more recent testing of five progressively deeper (from west to east) Nassau County Lloyd Aquiifer observation wells on the barrier beach areas (Busciolano and Terracciano, 2013) detected chloride levels ranging from 42 mg/L in Atlantic Beach to 110 mg/L in Long Beach, decreasing to 6 mg/L in Tobay Beach.

The USGS (Stumm, 2001; Stumm, et al, 2002 and 2004) has published three reports regarding the hydrogeological condition of the aquifers in Great Neck, Manhasset Neck, and the northern part of the Town of Oyster Bay where a total of eight wedges of saltwater intrusion were found, having peak chloride concentrations ranging from 180 to 13,750 mg/L. The USGS reports also identified the presence of the North Shore Aquifer in northern Great Neck, Manhasset Neck, and Oyster Bay. This aquifer was identified as a distinct hydrogeologic unit that is hydraulically interconnected with the Lloyd Aquifer.

The Lloyd Aquifer is threatened by continuing saltwater intrusion in southern and northern Queens and Nassau Counties that may be accelerated by the NYCDEP reactivation of four Queens County Lloyd Aquifer public supply wells which have an authorized capacity of 7.6 MGD. A 1993 potentiometric-surface map of the Lloyd Aquifer revealed a large cone of depression centered in Queens County around the 4 Lloyd Aquifer public supply wells, extending from western Nassau to eastern Kings Counties. This suggests that the cone of depression in southern Queens County resulting from Lloyd Aquifer public supply withdrawal (Buxton and Shernoff, 1995) has caused inland migration of saltwater and that the freshwater-saltwater interface may be about 7 miles further inland than previously estimated by Buxton and Shernoff.

LICAP is urged to recommend that the State of New York protect and preserve the Lloyd Aquifer in non-"coastal communities" by prohibiting the reactivation and issuance of any permits for Lloyd Aquifer wells that have not been used for water supply purposes for five or more years; prohibiting the replacement, relocation, deepening, or re-drilling of any Lloyd Aquifer wells; and by prohibiting the installation of new, replacement, or deepened wells into the North Shore Aquifer. It is also recommended that

the State of New York provide a permanent annual funding source to continue the USGS annual well monitoring program and consider the enactment of legislation that would provide on-going funding for continued research and improved management of the groundwater resources of Long Island to help preserve and protect the Lloyd and North Shore Aquifers and water resources of Long Island for future beneficial and sustainable use.

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